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APPLICATION OF EREP IMAGERY TO FRACTURE-RELATED MINE SAFETY HAZARDS IN COAL MINING AND MINING- ENVIRONMENTAL PROBLEMS IN INDIANA

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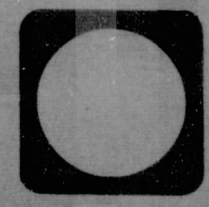
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16. Abstract The primary objective of this study, the comparison and evaluation of EREP and SKYLAB imagery for mine safety and surface mining environmental studies, was only partially accomplished due to the lack of access to underground mines necessary for the verification of fractures and lineaments mapped. The high resolution of the SKYLAB systems imagery provided substantial, and sometimes unique, information about lineaments and fractures in the test area. The imagery proved particularly useful for the mapping of areas of surface coal mining and assessing the regional environmental effects of such activity. <div style="text-align: right;">Original photography may be purchased from: EROS Data Center 10th and Dakota Avenue Sioux Falls, SD 57198</div>			
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APPLICATION OF EREP IMAGERY TO FRACTURE RELATED MINE SAFETY HAZARDS IN COAL MINING AND MINING-ENVIRONMENTAL PROBLEMS IN INDIANA

1.0 INTRODUCTION

The primary objective of this investigation was to evaluate and compare SKYLAB (EREP) and LANDSAT imagery for the detection of geological fractures and lineaments in areas covered by glacial drift and then to examine the location of these features in relation to areas of mining hazards. Due to the lack of operating underground coal mines within the test area, there was limited opportunity to compare fractures mapped on the imagery to mining hazards. Secondary objectives were directed to evaluating the application of LANDSAT-1 and EREP imagery to other mining problems such as mining progress and environmental assessments.

This investigation was conducted to complement the recently completed LANDSAT-1 investigation for the same test area, entitled "Application of LANDSAT-1 Imagery to Fracture Related Mine Safety Hazards in the Coal Mining Industry" which was conducted from July 1972 to July 1974 under NASA Contract NAS5-21795. As part of this investigation, the higher-resolution SKYLAB data have been compared to LANDSAT imagery for fault and lineament detection and for discriminating various degrees of mining activity, mine waste accumulation, reclamation activities, and other environmental problems related to surface mining in the Midwest.

New information on lineaments and fracture patterns in the bedrock of Indiana and Illinois was extracted from analysis of both EREP and LANDSAT imagery. Although general structural trends and fracture directions were well known prior to this and the LANDSAT-1 investigation, the presence of pronounced major lineaments or fracture systems in the central part of the Illinois basin was unsuspected. This information has contributed to furthering geological understanding of this portion of the Illinois Basin.

There is a close correlation between directions of lineaments mapped from EREP, LANDSAT, and complementary aircraft imagery, fractures measured on bedrock outcrops, and fractures measured in the underground mines. Operators of the Kings Station underground mine, a primary mine test site in the LANDSAT study, confirmed a correlation between actual roof falls and predicted roof falls as determined from satellite and aircraft image analysis. Based on these and other findings, major coal-producing companies in the eastern United States have begun evaluating the relationship between lineaments and roof falls in their underground mines. Some companies have been able to reduce mining costs by adjusting the direction of main entries to avoid the effects of excessive weakness of roof rock due to fractures.

Although the resolution of the EREP and LANDSAT data is such that only a few (extremely large) areas of mine subsidence can be detected directly, lineament data (indicative of zones of structural weakness) derived from these data can aid mapping subsidence hazards.

This experiment clearly demonstrates the utility of an integrated EREP, LANDSAT-1, and high altitude aircraft data analysis approach for a number of mining industry problems, including roof fall and mine subsi-

dence prediction, coal refuse inventory, mined land inventory, and monitoring reclamation status for coal, sand and gravel, clay, and other types of surface mined lands.

2.0 BACKGROUND

2.1 Historical Development of Investigation

In the spring of 1973, the Coal Section of the Indiana Geological Survey and Earth Satellite Corporation began an EREP investigation to complement the existing LANDSAT-1 experiment to test the feasibility of integrating fracture data (derived principally from satellite imagery and high-altitude aircraft photography) for application to coal mine safety and other coal-related problems. These investigations promised particular benefits to states within the Eastern Interior Coal Basin that are mantled by a glacial drift cover which ranges from a few feet to several hundred feet in thickness. In these areas, fracture mapping by conventional ground methods is costly and often impossible. Successfully demonstrated mapping techniques would also benefit other states where bedrock structure is obscured by a deep unconsolidated overburden.

2.2 Roof Fall Hazards in Underground Mining

Underground mining is generally more complicated and costly than surface mining; hazards to miners are also considerably greater. United States Bureau of Mines statistics identify roof falls as the primary cause of deaths in underground coal mining. Roof falls and rock bursts may account for only one or two fatalities in a single incident, but there are many such potentially deadly accidents.

A roof fall results when the roof rock falls into the opening created by the removal of the coal. Massive roof falls may fill the mine room or tunnel with rock rubble and leave a conical shaped hole extending upward as much as 30 feet. Anything that con-

tributes to weakening the supporting strength of roof rock will increase the likelihood of roof falls. Such factors include poor mining practices, and lithologic differences, rock expansion due to reduction of lithostatic pressure, i.e., the introduction of water. Significantly, a large number of roof falls result from rock weakened by fractures.

Mine operators cannot predict the presence and magnitude of fractures that they will encounter as mining progresses. Although coal companies commonly do extensive core drilling before they develop underground mines, such programs cannot provide sufficient data on the density and orientation of fractures to form a meaningful model of subsurface conditions.

2.3 Environmental Aspects of Mining

More than three million acres of land have been disturbed by surface mining in the United States excluding lands used for disposal of coal refuse, i.e., coal refuse banks and slurry ponds. The environmental effects associated with active surface mined areas are varied and depend upon (1) the length of time an area has been undergoing active surface mining; (2) the areal extent of surface mining; (3) the type of surface mining, e.g., coal, clay, sand and gravel, etc.; (4) the method of surface mining, e.g., open pit, area or contour; and (5) the degree to which a surface mined area has been reclaimed.

As surface mining proceeds, areas are stripped of vegetation and soil cover. The overburden is either spread downslope (in the case of contour mining in steep terrain) or placed in ridges on the

previously mined area (in the case of area mining in areas of low relief). Because the slopes are often devoid of vegetation, they are susceptible to gully erosion. Also slope instability may result in landslides and excessive stream sedimentation. Chemical weathering may produce toxic materials such as sulfuric acid that move downslope and into stream channels making waters unsuitable for aquatic life and unpotable to man.

These effects, because of their dynamic nature, require monitoring on a regular basis. Recent concern about the environmental effects of surface mining has produced public pressure for increased regulation of the surface mining industry to reduce adverse effects. Most state regulatory legislation currently in force has been enacted since 1965. Sixteen major coal states (including Indiana) surveyed for a report by the Council on Environmental Quality had taken twenty-eight major legislative actions between 1965 and 1972. Since 1970, 13 of the 16 coal states have enacted new legislation or amended previous laws. Over the past several years, there has been a general trend in state laws away from post-mining reclamation requirements to more extensive reclamation requirements that must be performed concurrent with the mining activity.

The enforcement of these laws requires the monitoring of all phases of the mining and reclamation activity, and for some states constitutes a major expenditure of manpower and money as staffs of nearly 150 field inspectors are maintained for this purpose. New technology and procedures which improve these states' monitoring capabilities and/or permits a reduction in operating costs is needed.

2.4 Previous Investigations

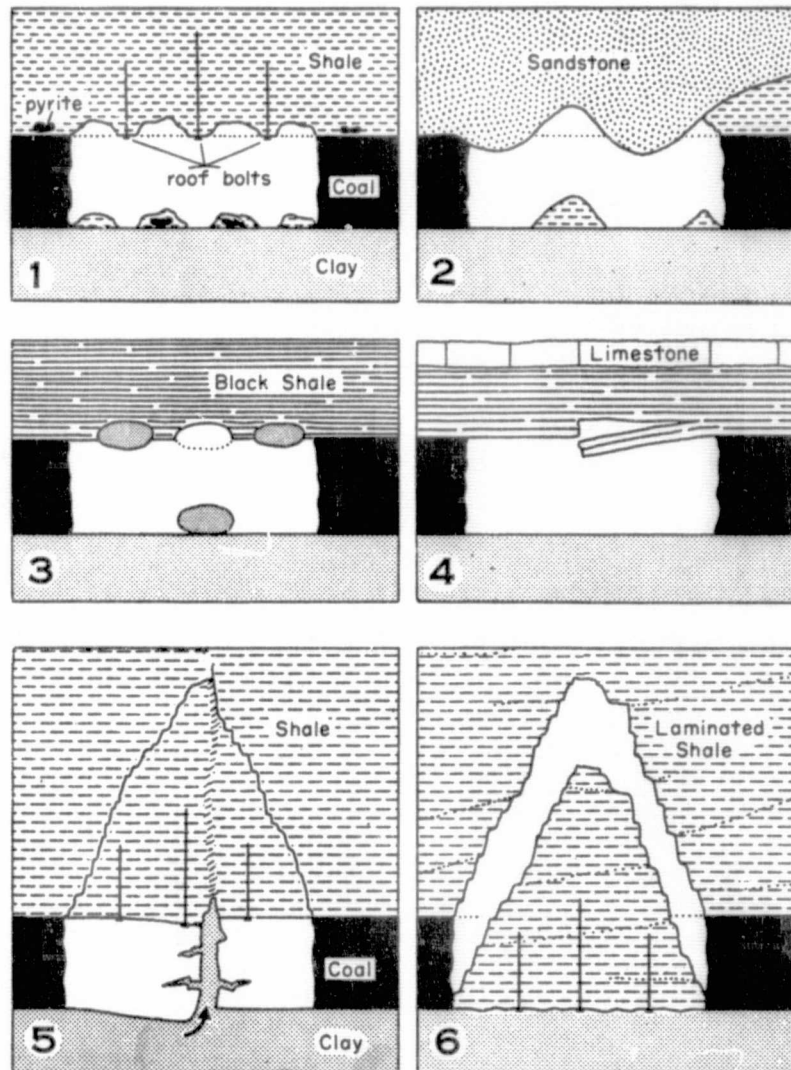
Roof falls in underground mines result from a complex variety of lithological and structural factors acting in combination to create a condition of roof instability. Wier (1970) conducted geological investigations in Sullivan County, Indiana, and identified six causes of roof fall (Figure 1), all of which were aggravated by associated fracturing. Overbey, et al. (1973) identified 12 factors contributing to roof falls, 5 of which are directly associated with jointing or faulting. Benedict and Thompson (1973) in investigations in western Pennsylvania report:

"First and foremost, we observed that numerous fall areas in the mine were commonly associated with or were outlined by fractures. A factor that was very apparent and that later turned out to be quite significant in combination with other geological criteria was the density of fractures, which varied widely from one location to another in the mine reserve under study."

Numerous other studies cited the significance of fracturing in relationship to roof falls; however, the above-referenced reports are the only systematic programs to evaluate fracture location, intersections and density with roof falls in underground coal mining.

2.5 Information Sources

The SKYLAB - EREP data evaluated in this investigation included the Multispectral Photographic Camera (S-190A) and the the Earth Terrain Camera (S-190B). Imagery received from the Multispectral



- | | |
|------------|------------------------------|
| Example 1. | <i>Dust roof fall</i> |
| Example 2. | <i>Lenticular roof fall</i> |
| Example 3. | <i>Concretion roof fall</i> |
| Example 4. | <i>Slate roof fall</i> |
| Example 5. | <i>Clay squeeze and fall</i> |
| Example 6. | <i>Massive roof fall</i> |

FIGURE 1 Examples of factors contributing to roof fall as identified in Indiana (Wier, 1970)

Scanner (S-192) did not cover the project area. After examination of this imagery, the quality and resolution was judged only marginally adequate for the project objectives and additional imagery was not requested. The S-190A data was received in both 70mm (1:2,863,596 scale) and 9 inch (1:715,798 scale) transparencies. Each frame of the S-190A imagery covers an area of 88 nautical miles square. The S-190A instrument contains 6 cameras, each equipped with a different film-filter combination (Table 1). The six cameras include two with panchromatic black and white film, two with black and white infrared film, one with color infrared and one with high resolution color film.

In 5 inch transparency format the S-190B imagery is at a scale of 1:955,535. Each S-190B image covers an area of 59 nautical miles square. This single lens camera acquired imagery over the test area with high - resolution aerial color film (SO-242) for track number 33 and color infrared film (EK-3443) for track 15. The color infrared film, with a Wratten 12 filter, has a spectral bandwidth sensitivity of .5 to .88 μ m. The high resolution color (SO-242) film has a spatial resolution of 50 feet, whereas the color infrared film has a spatial resolution of about 100 feet for target contrasts of 1.6:1. The S-190B imagery served as the primary satellite data source for this study and was used as a basic reference for comparison of other EREP and LANDSAT sensors.

EREP data was acquired during two overpasses over the Indiana-Kentucky test areas (Figure 2). The first overpass was made by SKYLAB Mission II Track 33, on June 10, 1973. Imagery provided from this track commences in western Illinois and extends into

Table 1A. Multispectral Camera Station Characteristics and Film Rolls Used. 1/

Sta	Filter	Filter Bandpass, micrometer	Film Type*	Estimated Ground Resolution††, feet (meters)	Mission & Roll No.		
					SL-2†	SL-3	SL-4
1	CC	0.7 – 0.8	EK 2424 (B&W infrared)	240 – 260 (73 – 79)	01‡,07,13	19,25,31,37,43	49§,55,61,67,73,A1,1B
2	DD	0.8 – 0.9	EK 2424 (B&W infrared)	240 – 260 (73 – 79)	02,08,14	20,26,32,38,44	50§,56,62,68,74,A2,2B
3	EE	0.5 – 0.88	EK 2443 (color infrared)	240 – 260 (73 – 79)	03,09,15	21,27,33,39,45	51§,57,63,69,75,A3,3B
4	FF	0.4 – 0.7	SO-356 (hi-resolution color)	130 – 150 (40 – 46)	04,10,16	22,28,34,40,46	52§,58,64,70,76,A4,4B
5	BB	0.6 – 0.7	SO-022 (PANATOMIC-X B&W)	100 – 125 (30 – 38)	05,11,17	23,29,35,41,47	53§,59,65,71,77,A5,5B
6	AA	0.5 – 0.6	SO-022 (PANATOMIC-X B&W)	130 – 150 (40 – 46)	06,12,18	24,30,36,42,48	54§,60,66,72,78,A6,6B

* Eastman Kodak Company

† SL-1 was the launch of Skylab without crew.

†† At low contrast

‡ Note that all roll numbers are 2-digit numbers. Single-digit numbers were used in other cameras.

§ Without filter

Table 1B. Earth Terrain Camera and Film Characteristics and Rolls Used

Film Type*	Wratten Filter	Filter Bandpass, micrometer	Estimated Ground Resolution††, feet (meters)	Mission & Roll No.		
				SL-2	SL-3	SL-4
SO-242 (hi-resolution color)	none	0.4 – 0.7	70 (21)	81	83,84,86,88	90,91,92,94
EK 3443 (SL-2 & SL-3) (infrared color)	12	0.5 – 0.88	100 (30)	—	87	—

* Eastman Kodak Company

† "Minus blue" filter

†† at low contrast

1/

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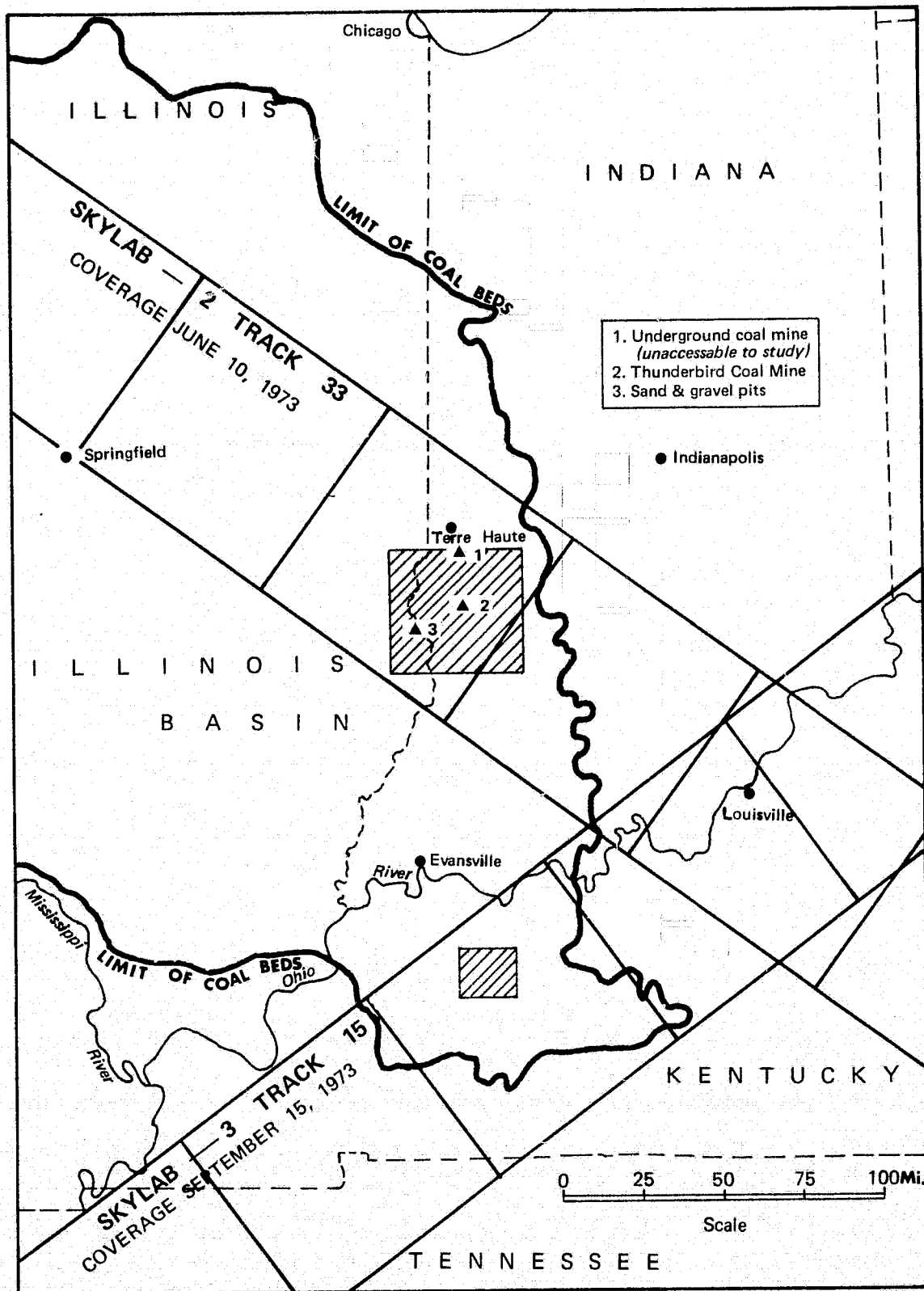


FIGURE 2. Map of Indiana and parts of Illinois, Kentucky, and Tennessee showing the extent of SKYLAB-ERE (S-190B) coverage and the location of the test sites for this investigation.

eastern Kentucky. The second overpass was made by the SKYLAB III Mission, Track 15, on September 15, 1973. The imagery received for this track begins in western Tennessee and extends into western Ohio.

On the basis of the imagery received, two test sites were established in the general test area (Figure 2). One site was selected in western Indiana, south of Terre Haute, and includes the Thunderbird mine (underground) and several large strip mines including the Minnehaha and the Dugger mines. Also included in this site are numerous sand and gravel pits, clay pits and several large crushed and dimension stone quarries. The second test site was selected in northwestern Kentucky in Muhlenberg and Hopkins Counties and includes several large active surface mines.

The SKYLAB photography was supplemented with LANDSAT imagery, and for the Indiana test site, with 1:120,000 scale color infrared photography acquired by NASA in 1971 as part of the Corn Blight Watch.

3.0 ANALYSIS PROCEDURES

3.1 Methodology

Numerous analytical techniques were used to augment standard visual analysis of LANDSAT, SKYLAB and aircraft imagery. These procedures included monoscopic visual analysis, stereo analysis, film sandwiching^{1/}, multi-band additive color projection^{2/}, density slicing/color coding^{3/} and Ronchi grating analysis^{4/}.

1/

Film sandwiching consists of producing a positive and negative film image of the same scene at the same scale. The two images are superimposed and offset a small amount. This produces a base-relief effect and enhances in one direction tonal boundaries. Linear features are particularly enhanced and made more obvious.

2/

Multiband or multispectral imaging involves the acquisition of two or more images of the same scene, usually recorded simultaneously in different regions of the visible and near infrared portions of the electromagnetic spectrum. With an additive color viewing system for multi-band aerial photography and satellite imagery, an operator can change both the intensity and color of the image during projection by adjusting the illumination and filters for each of the images which form the composite. Film-filter combinations may be used to produce special effects for the enhancement of specific features.

3/

This system enhances subtle image tone differences that are difficult to detect by normal visual inspection. The image is scanned with a high quality black and white television camera. The difference in film density is proportionally converted into a voltage signal. This signal is digitally incremented into a series of discrete voltage levels, and a different color is assigned to each voltage level. This incrementing of voltages is often referred to as "density-slicing" - a term frequently applied to this system.

4/

Pohn (1969) and Elder (1972) reported that a Ronchi grating can be used to enhance fractures. By viewing a photograph with a 200-line Ronchi grating positioned 12 to 18 inches from the photograph and approximately one inch in front of the eye, images are refracted normal to the ruled lines and are observed slightly offset on each side of the real image. This displacement emphasizes linear features oriented normal to the grating lines. Rotating the grating during viewing, emphasizes preferred orientations of joint or fracture controlled features, such as stream drainage.

All LANDSAT, SKYLAB and aircraft images were analyzed using manual methods including magnification of transparencies and prints and oblique viewing of prints and transparencies. The imagery was analyzed for geological data such as faults and lineaments and generalized glacial drift cover extent as well as for a variety of surface mining monitoring applications. Factors examined included the delineation of total disturbed land, mine refuse detection and mapping, the monitoring of active mining and land reclamation and revegetation progress.

Stereoscopic analysis of aircraft imagery aided detection of subtle linear features indicative of fractures and lineaments. Many of these features consisted of depressions lacking well defined tonal changes and thus detection was improved with stereo viewing. Oblique viewing of an image aided in the detection of apparently disassociated fracture-lineament segments. Figure 3 is a representative example of the 1:120,000 scale color infrared photography used.

Discrimination and inventory of mined lands were best accomplished by visual techniques. A coal refuse bank (gob pile) and slurry pond inventory of the Indiana coal field was conducted using visual and optical enlargement methods on small scale aircraft photography. Stereoscopic analysis of aerial photography was the primary analysis technique used for the discrimination of heavily revegetated surface mined lands and for making gross volumetric estimates of waste material at coal refuse sites.

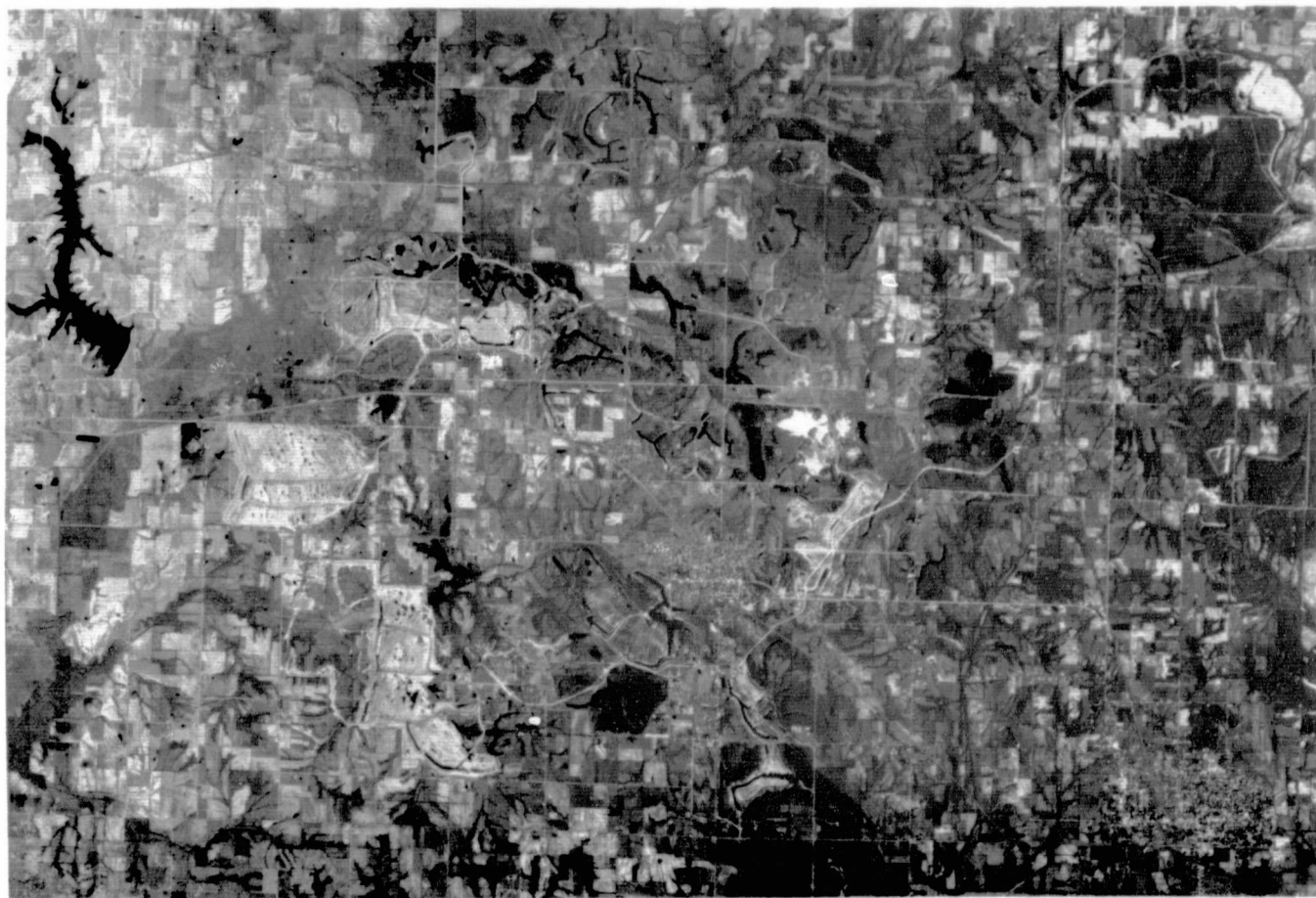


FIGURE 3. This is an example of the small scale (1:120,000) color infrared photography of the Sullivan, Dugger, Linton area of Indiana used for "ground truth" reference in this investigation. Much detail is discernable concerning the status of mining, grading and revegetation. The mine at left center is the Minnehaha shown on the S-190B enlargement in Figure 11. Note the advance in mining in this mine during the interval from 1971 (This photo) to 1973 (SL-2).

LANDSAT and SKYLAB S-190A multispectral^{5/} image sets were viewed on the Addcol with a variety of filter combinations. With such a system the operator can change both the intensity and color of the image during projection by adjusting the illumination and filter for each of the images which form the composite. Film-filter combinations may be used to produce special effects for the enhancement of specific features. However, none of the color presentations increased the lineament detection capability over the use of the individual images and usually reduced the operators ability to detect these features.

The I²S Digicol electro-optical system was used in this investigation to enhance black and white or color images by digitally slicing image density levels and displaying these density differences into as many as 32 colors on a color CRT display. Digicol analysis of LANDSAT and EREP imagery indicated that color coding of density levels is of little value for improving detection of subtle lineaments.

LANDSAT and EREP images were also viewed using a 200-line Ronchi grating positioned 12 to 18 inches from the image and approximately 1 inch in front of the eye. This technique was most effective for accentuating macro-trends, but it made only a limited contribution to lineament analysis in Indiana where the terrain has only moderate relief and many of the numerous cultural features possess a marked linear character. The advantages of this tech-

^{5/}

Multiband or multispectral imaging involves the acquisition of two or more images of the same scene, usually recorded simultaneously in different regions of the visible and near infrared portions of the electro-magnetic spectrum. Comparison of the relative amounts of spectral energy reflected or emitted by discrete objects in the scene is used to identify specific subjects and phenomena.

nique are largely offset by the high percentage of false lineaments indicated which were actually cultural features.

Comparisons were made among all the satellite imagery available at the two individual test sites. S-190B high resolution photography and the aircraft acquired color infrared photography also were compared. Because of the substantially higher resolution of the larger scale aircraft photography the aircraft imagery was used as the primary data base for checking interpretations of the SKYLAB and LANDSAT imagery.

3.2 Lineament Mapping

The few bedrock exposures are in the coal field area of southwestern Indiana are largely confined to a few isolated outcrops along streams. Man-made exposures in road cuts are not common, but numerous exposures have been created in the process of surface coal mining. In support of this investigation, the Coal Section of the Indiana Geological Survey made an extended effort to acquire strike measurements of fractures in such exposures.

The opportunity to measure fractures in underground mines was limited. Four underground mines were operating in Indiana in 1971. The Thunderbird Mine closed that year due to excessive roof fault problems. The Kings Station Mine closed in 1974 and currently only one underground mine is operational in the state.

SKYLAB imagery was acquired over the northern portion of the Indiana coal field and an area near Terre Haute, photographed during SKYLAB II mission, was selected as the test area. This area

was an excellent test site, not only for lineament mapping, but for the evaluation of SKYLAB imagery for mapping the extent and effects of surface mining because of the presence of (a) several large active surface mines, (b) large areas of older reclaimed and unreclaimed mined land and (c) two underground coal mines (Figure 2). This area also has several large sand, gravel, and clay pits.

The Terre Haute-Sullivan area was analyzed extensively for lineament data with both LANDSAT and aircraft imagery as part of the companion LANDSAT study; these data are presented in Figure 4.

During the analysis of the LANDSAT coverage it was observed that the surface condition of the land and the varied development of the vegetational cover influenced the detection of lineaments in this area; late spring was a particularly opportune time for image acquisition. The area near Terre Haute is largely cultivated farm land, which in mid-June was essentially devoid of a vegetative cover. This permitted the detection of soil tonal anomalies that would be obscured later in the season. Many of the streams in this area appear structurally controlled, and the natural vegetation along these streams contrasts with the bare field emphasizing the unusually straight character of many of the natural drainageways.

These factors had essentially the same influence on the lineament detection capabilities on the S-190B imagery. The SKYLAB II overpass occurred at an optimum time of year for lineament mapping in this particular area. If the area had been more densely covered by vegetation as that of the southeast, the value of the imagery for lineament detection would have been substantially less.

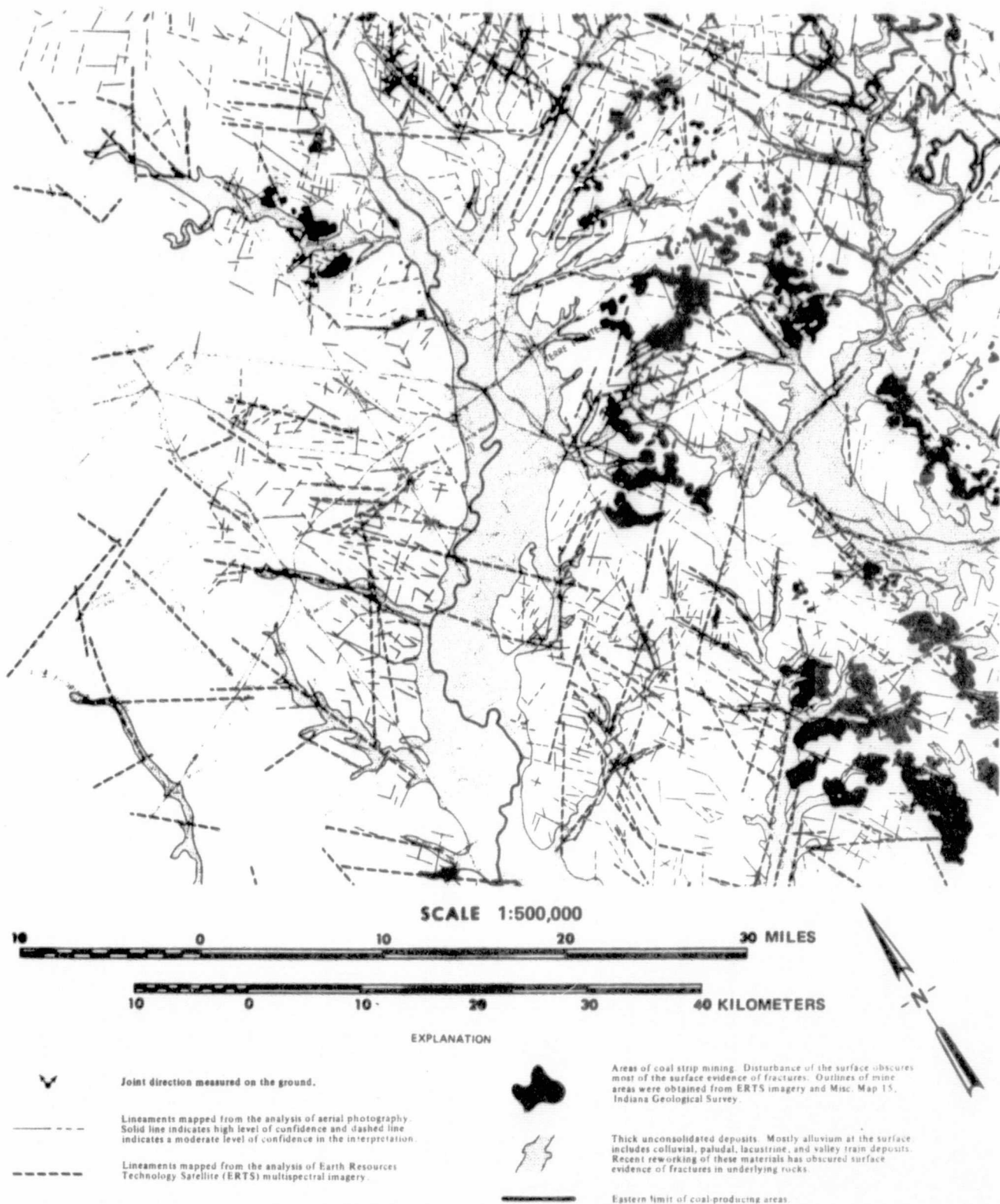


FIGURE 4. Geological lineament map of a portion of the 1° by 2° Indianapolis quadrangle, Indiana and Illinois. This map, reduced to 1:500,000 from an original scale of 1:250,000, shows lineaments mapped from analysis of LANDSAT-1 imagery and aerial photography. Also shown are field measured joint azimuths, areas of surface coal mining and major alluvial deposits.

S-190B imagery was acquired of the test area with SO-242 film which was judged somewhat inferior to the color infrared emulsion [EK-3443] for lineament detection and for surface mining studies as well. In spite of this, numerous lineaments were detected on the S-190A and S-190B imagery that were not discernible on the LANDSAT imagery. Within the test area the combined analysis of 18 months of LANDSAT imagery reveals 165 lineaments, whereas, from the imagery from the single overpass of SKYLAB II, 257 lineaments were mapped. Of the S-190A imagery the red spectral band imagery proved of particular value in lineament analysis. The combined results of the analysis of the S-190A and S-190B is shown in Figure 5.

As part of the LANDSAT study, rose diagrams of lineaments measured on LANDSAT imagery in the area of the Thunderbird Mine (Figure 6A) and on small scale color infrared photography (Figure 6B) were compared with fractures measured in the Thunderbird Mine (Figure 6C). The rose diagrams of the various fracture-lineament data measured in the Thunderbird Mine area show good correlation, particularly for the prominent trend of N 40-50 E. A rose diagram of lineaments measured on SKYLAB imagery throughout the test area (Figure 7A) also compare favorably indicating a high degree of validity for the features mapped even though many of the lineaments mapped on SKYLAB and LANDSAT imagery do not coincide. It is interesting to note, however, that a prominent fracture trend of N 70-80 W was mapped in the mine which was not detected on any of the imagery, regardless of scale. A possible explanation for this is that as a statistically small number of measurements were available from the mine, emphasis of this trend may be the result of a unique localized development of joints.

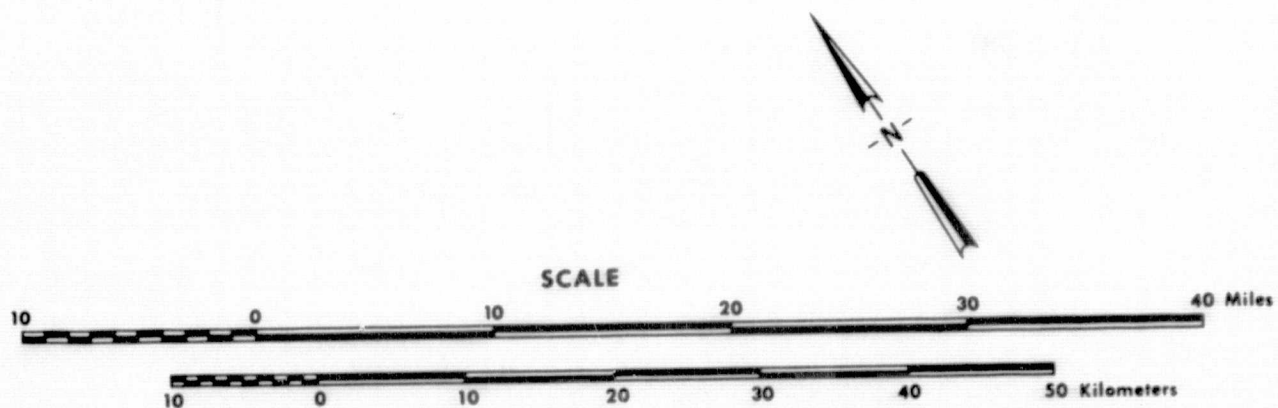
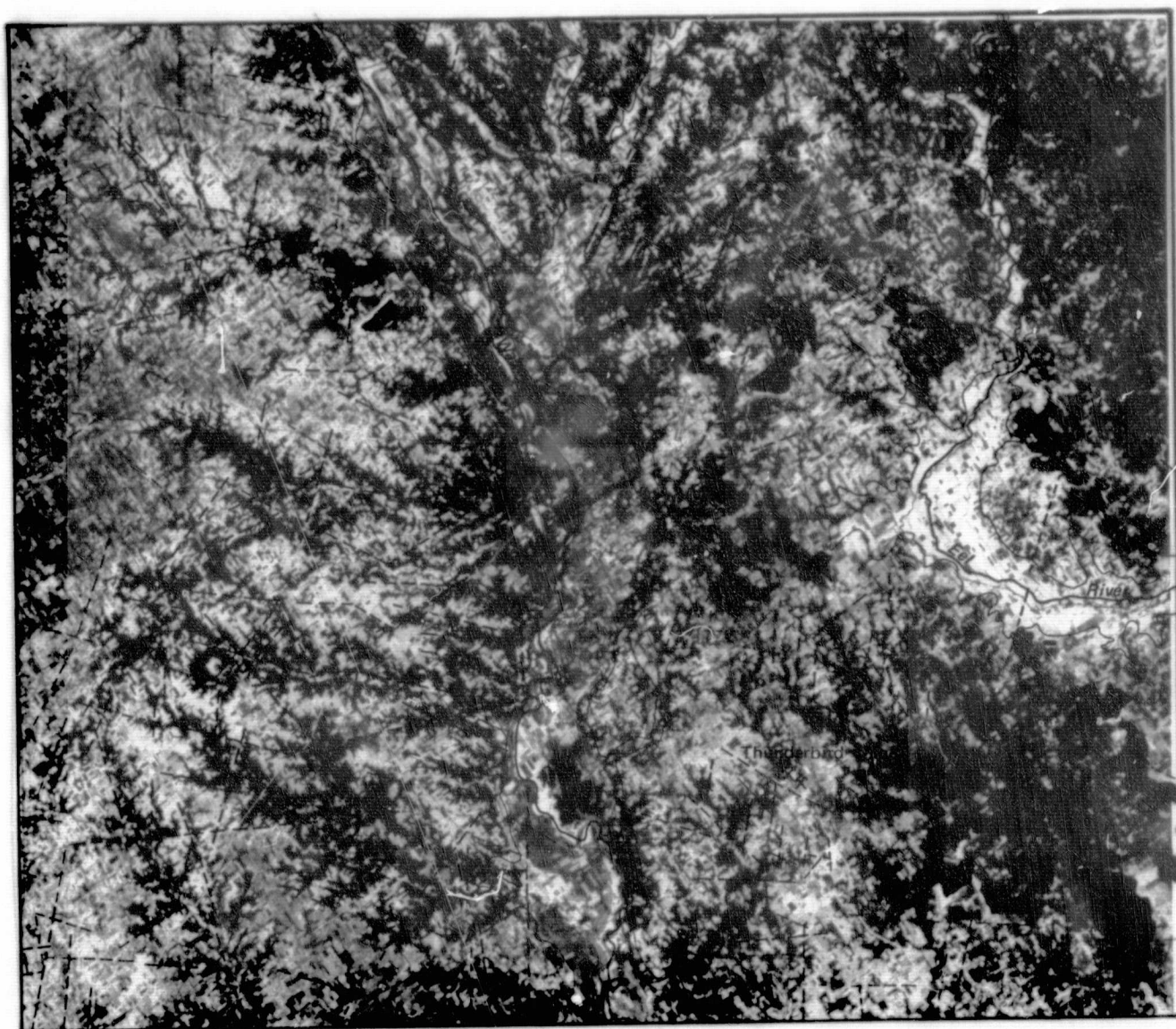


FIGURE 5. An enlargement of a portion of the red band S-190A image (No. SL-2, 241, RL-11) with a geological lineament map overlay. This image corresponds to the same area shown in Figure 4. This map shows the lineaments mapped from the combined analysis of S-190A and S-190B imagery.

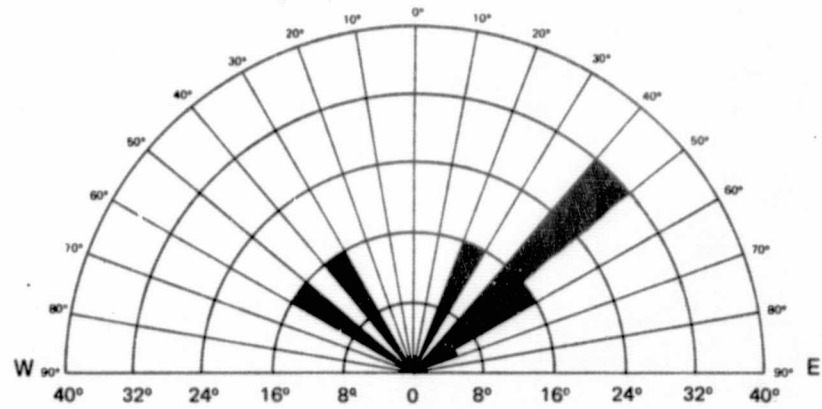


FIGURE 6A. Lineaments measured on LANDSAT imagery in the Thunderbird Mine area (20 measurements).

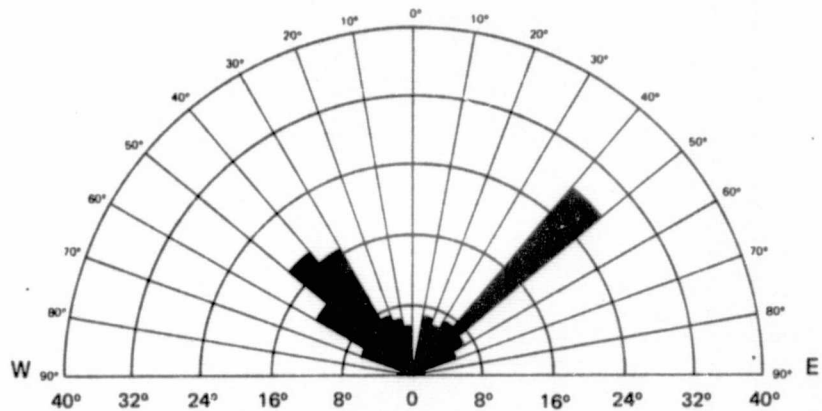


FIGURE 6B. Fracture-lineaments mapped in the Thunderbird Mine area from 1:120,000 scale color infrared photography (98 measurements).

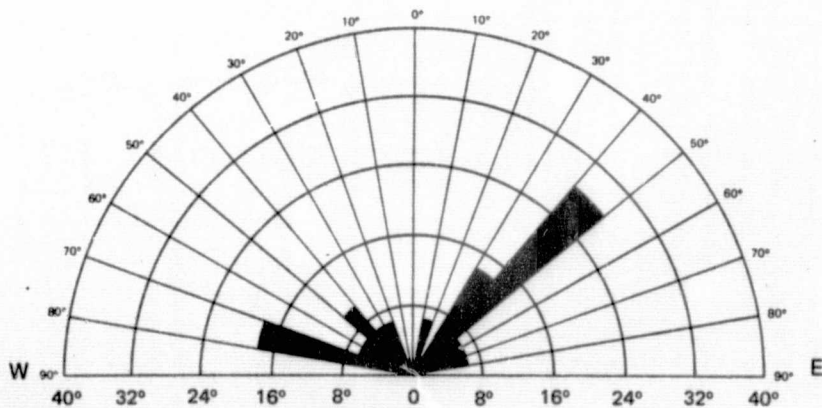


FIGURE 6C. Fractures measured in the Thunderbird Mine in Coal Seam VI (19 measurements).

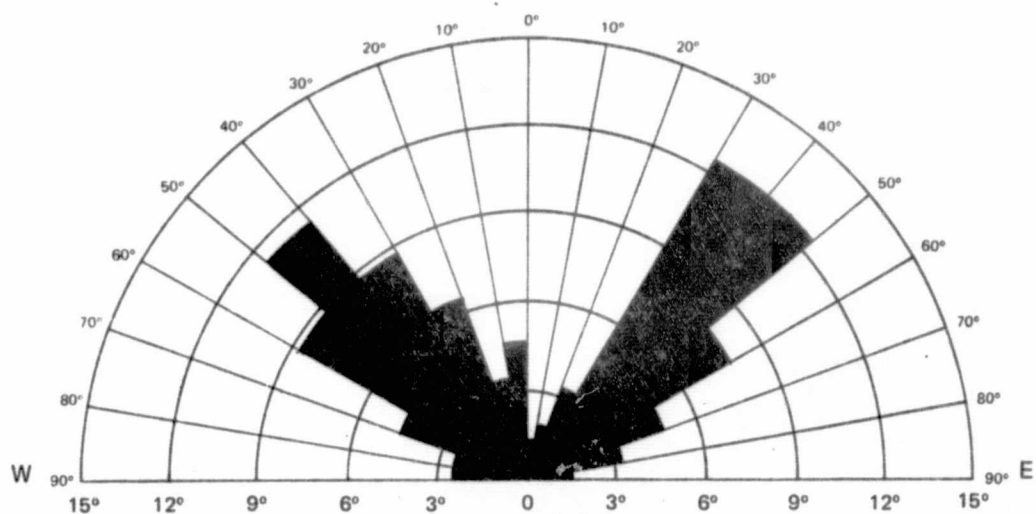


FIGURE 7A. Lineaments measured on SKYLAB imagery in the Indiana test site area (257 measurements).

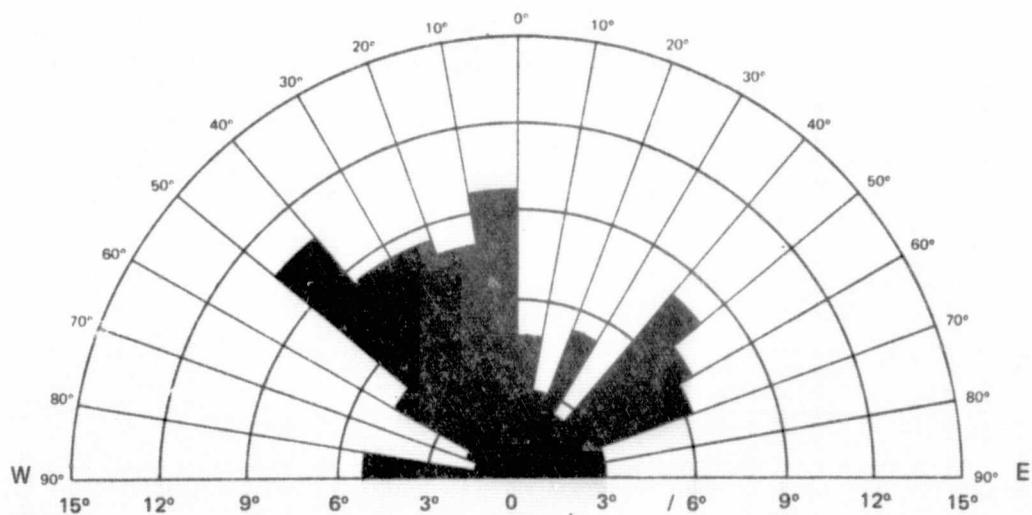


FIGURE 7B. Lineaments measured on LANDSAT imagery in the Indiana test site area (165 measurements).

A rose diagram of lineaments measured on LANDSAT imagery of the entire test area (Figure 7B) indicate a greater random scatter than for those measured in the vicinity of the Thunderbird Mine (Figure 6A). Although the predominant trends N 40-50 E and N 40-50 W are still evident in this plot, the diagram also indicates a prominent lineament trend of N 1-10 W which is not apparent from other sources. Care was taken during image analysis to avoid the effects of cultural features, however, it appears probable that the landnet may have influenced the mapping of some lineaments.

Although the correlation of the lineament data derived from the different sources is good, the significance of the lineament-fracture information for mine safety and the prediction of roof falls in coal mines is impossible to adequately assess. The Thunderbird mine is within this area, but as operations ceased in 1971 the only underground measurements of fracture trends available from this source were those made by the principal investigator a few years previously. As a consequence, there was no opportunity to observe directly the correlation between mapped lineaments or mine fractures and actual roof falls with a mine.

3.3 Surface Coal Mine Studies

Surface mining for coal is extensive in southwestern Indiana in areas where coal seam depth is less than 100 feet. LANDSAT imagery had a demonstrated utility for mapping the aerial extent of such mining and to make some judgements as to the status of reclamation. An example of LANDSAT imagery (No. 1033-15591-7) enlarged to approximately 1:250,000 is shown in Figure 8 for comparison pur-

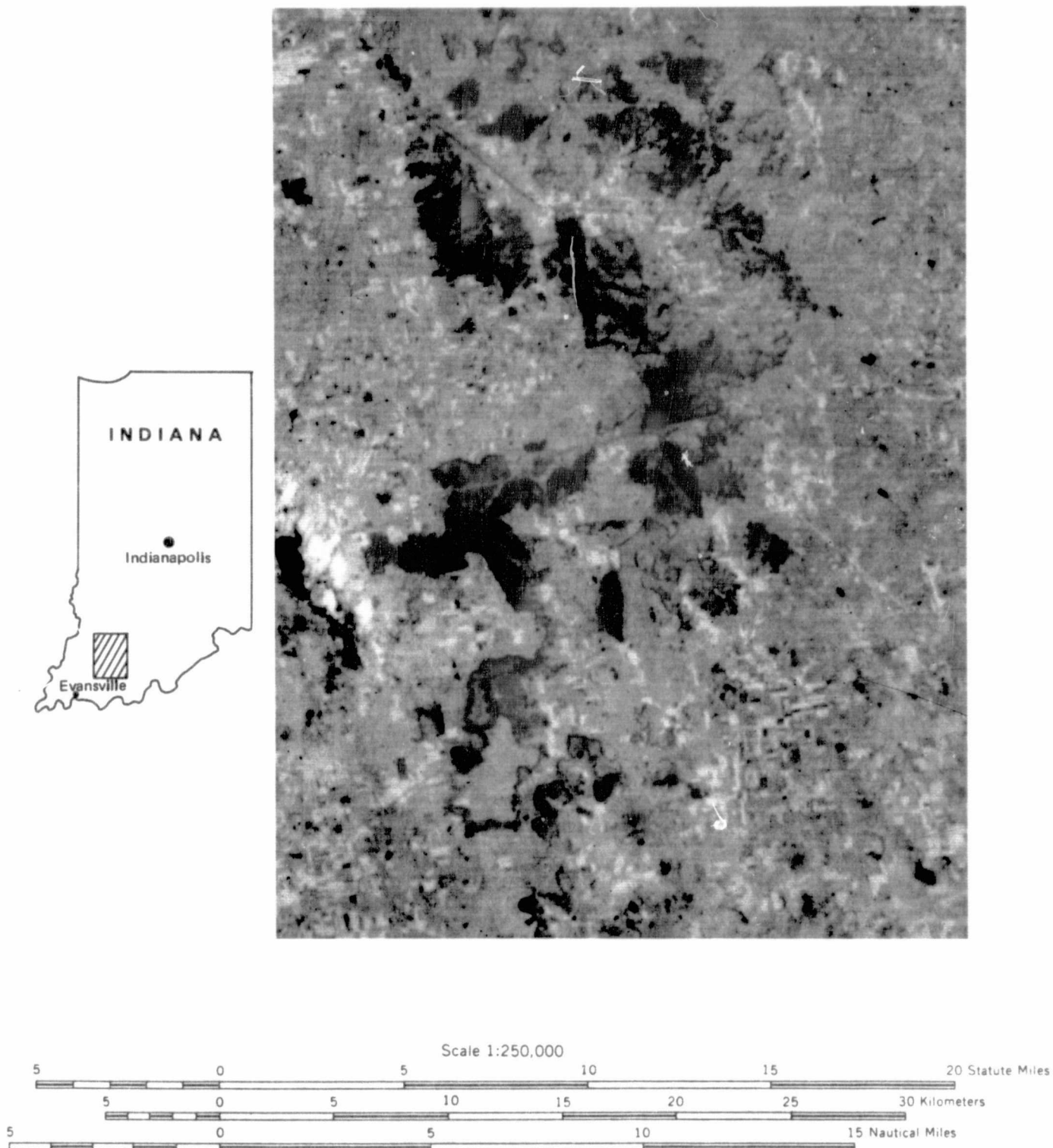


FIGURE 8. LANDSAT image (1033-15591-7) of the Lynnville, Indiana area enlarged to approximately 1:250,000 scale showing the areas disturbed by surface mining for coal. This imagery provides a means of rapidly mapping and frequently updating mined land areas.

poses. This image was acquired on August 25, 1972. It shows the disturbed lands of surface mining, refuse piles, slurry ponds, and haul roads in broad detail. Changes in aerial extent of mining are discernible as in Figure 9. This map was produced by superimposing the mined land boundaries derived from the LANDSAT image with a conventional mined land map published in 1968. In this mapping, isolated mined land areas of less than 10 acres extent were difficult to identify as were mined lands with $\leq 60\%$ revegetation cover.

3.3.1 Sullivan, Indiana Test Site

S-190A and S-190B SKYLAB photography of the Sullivan, Indiana area were evaluated for utility for surface mined land investigations.

Black and white and color enlargements of the S-190B color and color infrared imagery were made to determine the maximum scale to which the imagery could be enlarged without excessive image deterioration and to determine the optimum scale(s) for visual analysis. To test the utility of different image scales for analysis of mined land features, photographic enlargements were made to scales of 1:500,000, 1:250,000 (Figure 10A), 1:100,000, 1:50,000, and 1:24,000; the latter a 40X enlargement. The 1:250,000 and 1:100,000 scale enlargements proved most useful for this investigation. Utility of the 40X enlargement (1:24,000 scale) is discussed later.

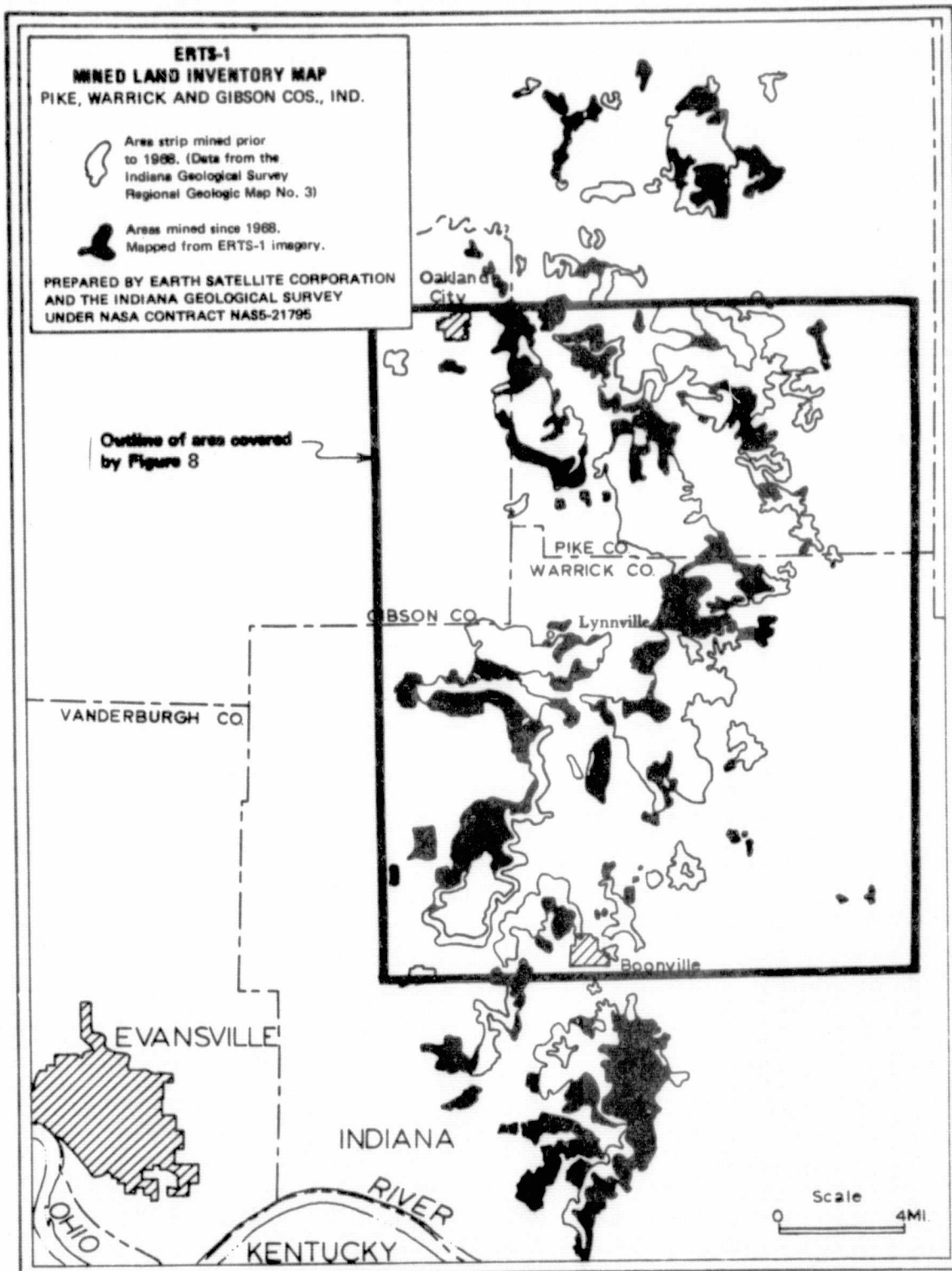


FIGURE 9. Mined land inventory map of southern Indiana updated by LANDSAT imagery.

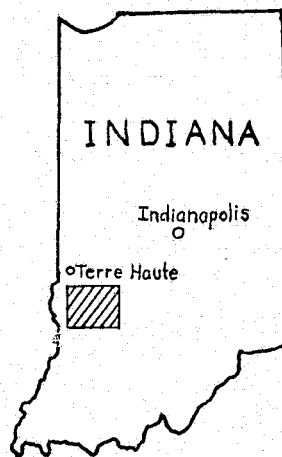
A 1:250,000 scale enlargement of SKYLAB-II S-190B color imagery was prepared to compare strip mining progress with a recently published (June, 1972) strip mine area map of Indiana (Figure 10B). This analysis revealed significant advances of strip mining in the Dugger, Jasonville, and Sullivan areas, and the opening of a new mine near Hymera. Land which has been strip mined and reclaimed recently (within the past 5 years) is evident; however, older mined lands overgrown with trees were difficult to differentiate on the S0-242 film from the nearby unmined farm and forest lands. Changes in mined area as small as 2 acres could be identified visually on the imagery.

This can be compared with LANDSAT imagery enlarged to 1:250,000 scale over the Lynnville, Indiana area (Figure 8) and the accompanying mined land inventory map (Figure 9) for the area of the image (outlined in black). Although LANDSAT does not provide the resolution and data quality of SKYLAB, its repetitive coverage and computer processing compatibility make it useful for rapidly updating existing mined land maps and data.

Analysis of the 1:100,000 scale black and white S-190B enlargements showed that nearly all past and current surface mining could be accurately delineated and that one or two classes of reclamation assessment could be detected. Cultural detail at this scale was adequate for either making new base maps of the area or positioning the mine delineations accurately on existing base maps.

FIGURE 10.

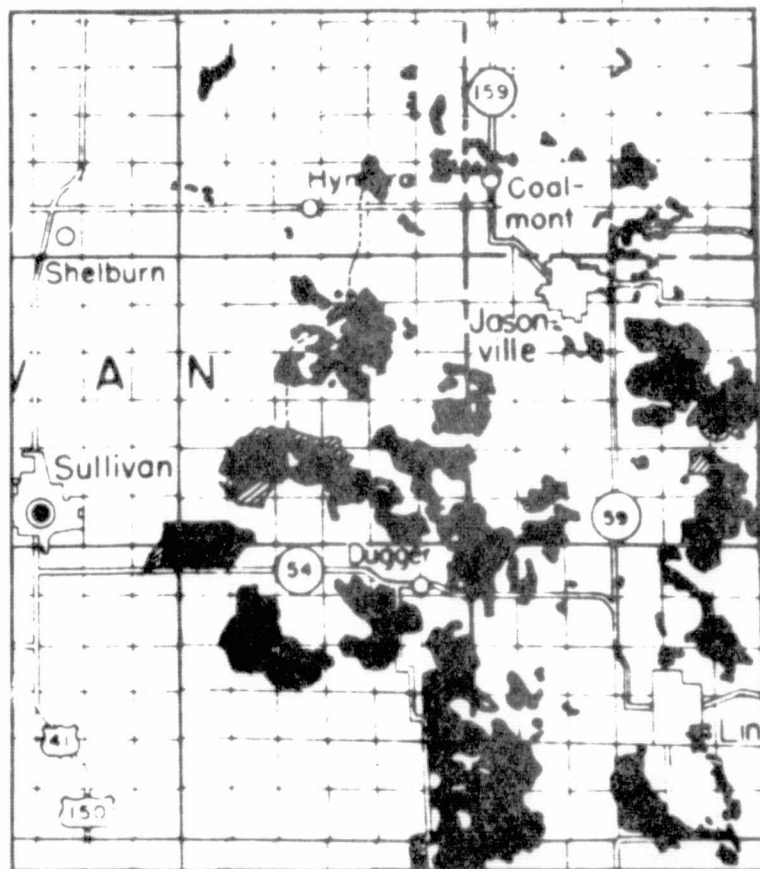
- A. Reproduction of SKYLAB S-190B color imagery (SL-2, 81-338) acquired on June 10, 1973, enlarged to a scale of 1:250,000 showing recent strip mining for coal in the area east of Sullivan, Indiana. The location of this area is shown in the diagram below. Older strip mines in the center of the image are not evident as they have become overgrown by trees and blend with the surrounding forested lands.



- B. Portion of a map ^{6/} published by the Indiana Geological Survey of the same area and scale as the image shown above delineating areas strip mined for coal up to June, 1972. The areas shaded by diagonal lines indicate areas which have been strip mined during the year between the map compilation and the SKYLAB II overpass.

6/

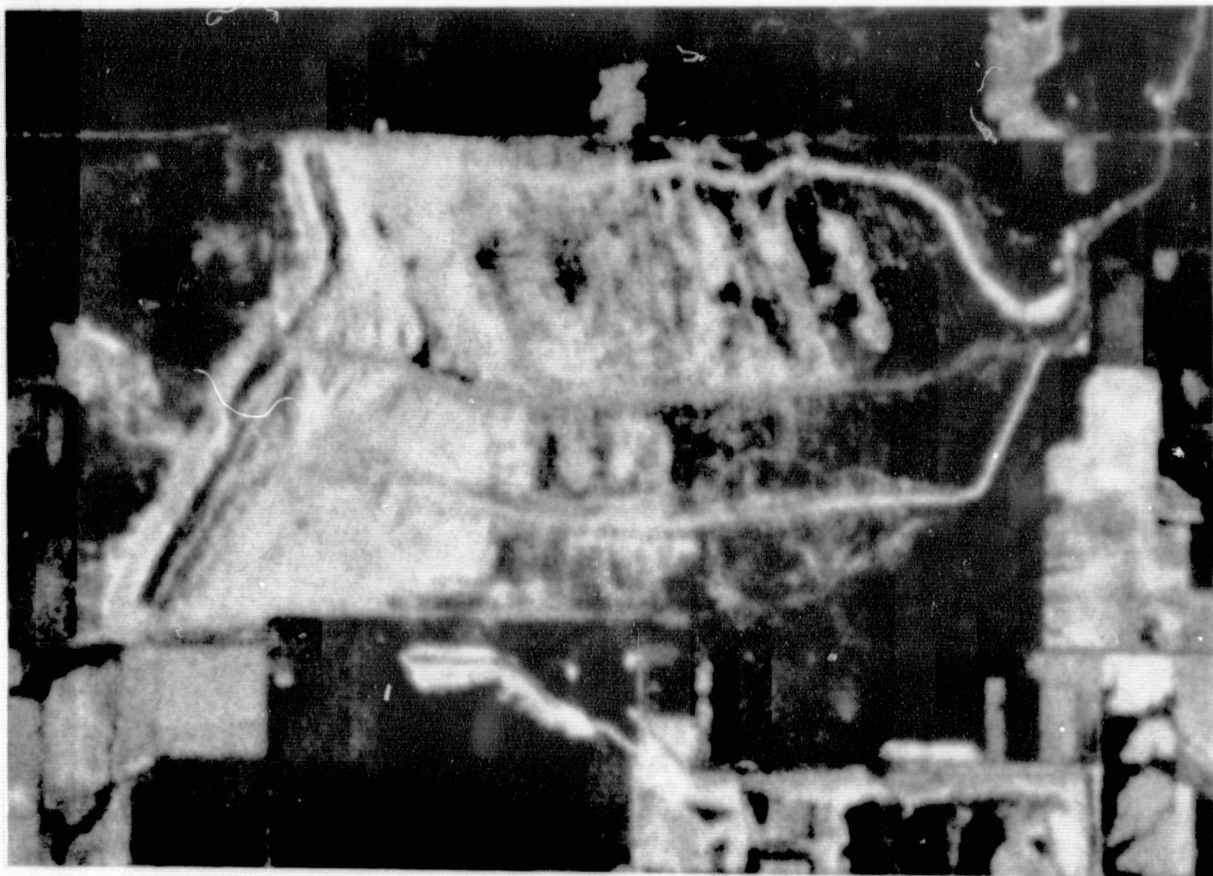
Powell, R. L., 1972. Map of Southwestern Indiana Showing Areas Strip Mined for Coal. Indiana Geological Survey, Miscellaneous Map No. 15.



A 1:24,000 enlargement was made of the large, active Minnehaha Mine to determine if SKYLAB data was suitable for updating existing large scale mined land maps or for producing new quadrangle-sized, photobase, mined land maps. The 1:24,000 scale enlargement (Figure 11) is about the maximum enlargement permissible for SKYLAB S-190B imagery without excessive image deterioration. Although the mined areas could be readily delineated (especially where high contrast exists between the freshly mined soil and rocks and the much darker surrounding vegetation), the resolution of the enlargement at this scale is probably not adequate to produce the detail and accuracy necessary for most state agency needs. At this scale high contrast mined areas could be delineated with a tolerance of plus or minus 1/30th of an inch (\pm 67 ft.) whereas some of the lower contrast previously reclaimed areas could only be delineated with a line accuracy of about 1/10th of an inch (200 ft.).

3.3.2 Millport, Kentucky Quadrangle Test Site

The Millport Quadrangle test site was selected because EarthSat had previously investigated the area and had acquired considerable ground truth data. This site is situated at the southeastern extremity of the Eastern Interior Coal Basin and is located about midway between Madisonville and Central City, Kentucky. This area, with its thin soil cover and bedrock exposures, contrasts with the Sullivan test site which



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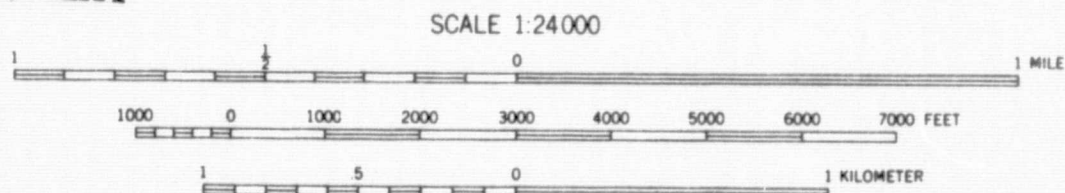


FIGURE 11. A 1:24,000 scale enlargement of a SKYLAB S-190B color image (SL-2, 81-338) of the large Minnehaha surface mine in the Sullivan, Indiana test site. A large dragline used for removing the overburden can be distinguished at (A) as can be the highwall and the current mining furrow. Two ridges of ungraded mine spoil are evident at (B). Land reclaimed under old mining laws which did not require the ridges to be leveled is identifiable at (C). The old and current haul roads are obvious at (D). The older, now unused, road is imaged with less contrast.

is overlain with a glacial drift cover several feet thick. A mined land inventory map was prepared at 1:24,000 scale using quadrangle centered 1:80,000 scale panchromatic photography acquired in 1971 by Mark Hurd Aerial Surveys (Figure 12). LANDSAT and SKYLAB imagery were evaluated for possible use in updating this map. A 1:24,000 scale enlargement was made from S-190B color infrared imagery of this 7-1/2' quadrangle area, and enlargements to 1:80,000 scale were made of both SKYLAB (Figure 13) and LANDSAT (Figure 14) imagery to compare directly with the high altitude aerial photographs. The SKYLAB imagery was acquired on September 15, 1973, whereas the highest quality LANDSAT frame for this same area, and the one used in this study, was acquired on September 30, 1972. Mined land maps prepared from the aircraft, SKYLAB and LANDSAT images formed the basis for determining the detail of delineation possible with each type of imagery. The 1:80,000 scale aerial photography (Figure 15) permitted mapping twenty-two separate categories of mined land disturbances, reclamation and mining features. These categories included areas of active strip mining, three categories of vegetative cover where no reclamation grading had occurred, three classes of vegetative cover where only partial grading had occurred, three vegetative cover classes where complete reclamation grading had occurred, three vegetative cover classes for graded and ungraded contour mining, along with the identification of water bodies, coal preparation areas, coal refuse

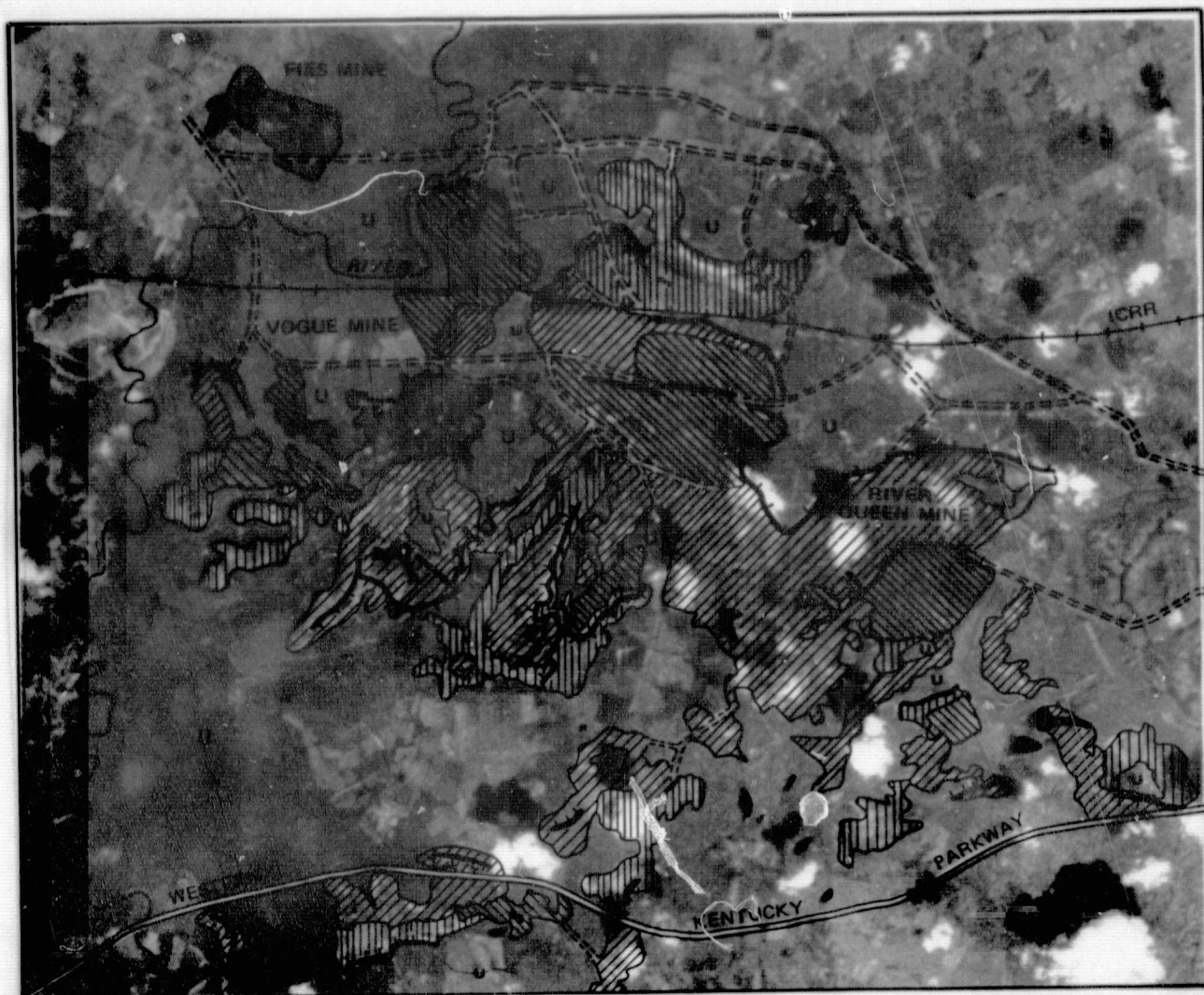
FIGURE 12

A portion of a 1:24,000 Mined Lands Inventory map prepared by EarthSat's photo analysts from high quality, small scale (1:80,000) black and white aerial photography. Areas of mining disturbance, their reclamation status and other mining-environmental features have been annotated as shown in the Legend below:

LEGEND

110	STRIP MINING,	ACTIVE		
111	STRIP MINED,	NO GRADING	0-25%	VEGETAL COVER
112	STRIP MINED,	NO GRADING	25-50%	VEGETAL COVER
113	STRIP MINED,	NO GRADING	50-75%	VEGETAL COVER
121	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	0-25%	VEGETAL COVER
122	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	25-50%	VEGETAL COVER
123	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	50-75%	VEGETAL COVER
131	STRIP MINED,	GRADED, ROLLING TERRAIN	0-25%	VEGETAL COVER
132	STRIP MINED,	GRADED, ROLLING TERRAIN	25-50%	VEGETAL COVER
133	STRIP MINED,	GRADED, ROLLING TERRAIN	50-75%	VEGETAL COVER
210	CONTOUR MINING,	ACTIVE		
211	CONTOUR MINED,	NO GRADING	0-25%	VEGETAL COVER
212	CONTOUR MINED,	NO GRADING	25-50%	VEGETAL COVER
213	CONTOUR MINED,	NO GRADING	50-75%	VEGETAL COVER
231	CONTOUR MINED,	GRADED, ROLLING TERRAIN	0-25%	VEGETAL COVER
232	CONTOUR MINED,	GRADED, ROLLING TERRAIN	25-50%	VEGETAL COVER

L - LAKE OR POND
P - COAL PREPARATION PLANT
S - SLURRY REFUSE AREA
G - GOR REFUSE AREA
D - DISTURBED AREA ASSOCIATED WITH PREPARATION PLANT
HIGH WALL



EXPLANATION



U	Unmined		Coal Refuse areas
	Mined, 50 - 100% revegetated		Highwall
	Mined, 1 - 50% revegetated		Haul Roads for Mining
	Mined, essentially bare soil		Water body

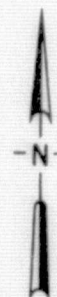


FIGURE 13. This image is a 1:80,000 scale enlargement of a SKYLAB S-190B color infrared photograph (SL-3, 87-049) acquired in September, 1973 over the Millport, Kentucky test site. Although a few scattered clouds appeared on the imagery, the quality and resolution were sufficient to permit mapping of eight categories of mined land disturbance as shown on the overlay.

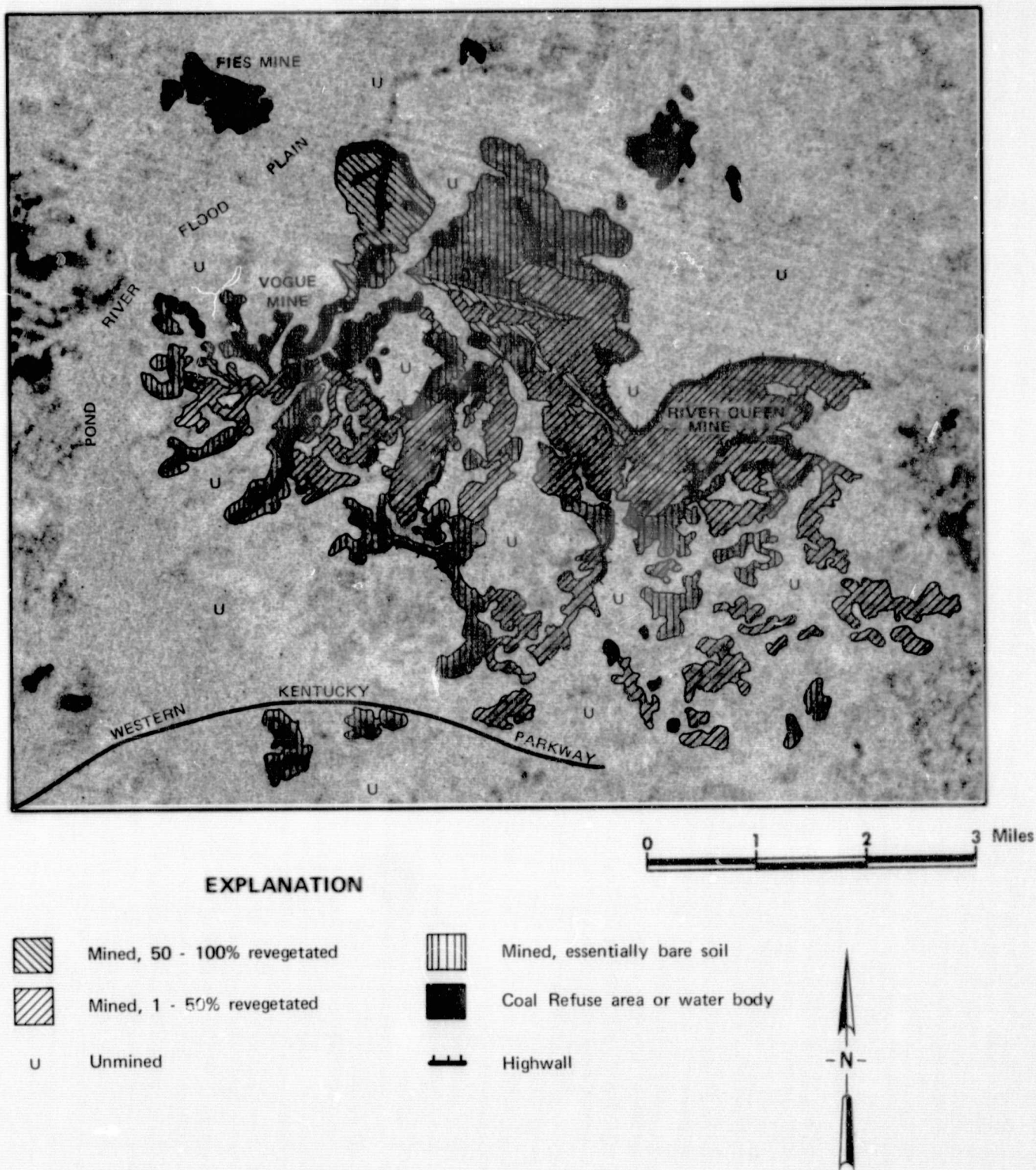


FIGURE 14. LANDSAT-1 image of Millport, Kentucky area enlarged to approximately 1:80,000 scale. This Band 7 image (No. 1069-15594) was acquired on September 30, 1972 and provides some of the highest contrasts between mined and unmined lands seen on LANDSAT-1 imagery of this test site. It was possible on this image to delineate six different categories of lands associated with surface coal mining.

areas, delineation of high walls, and the identification of areas disturbed by mining activities although not actually mined.

The enlarged SKYLAB imagery allowed discrimination of eight categories of mining activity and reclamation (Figure 13 overlay). These include areas which have been mined but are essentially bare soil and rock, areas mined with 50 to 100% revegetation, areas that have been mined with less than 50% revegetation, unmined areas, refuse areas and slurry ponds, water bodies, highwalls, haulage roads and other types of activity associated with the mining of the coal. The investigators could not identify contour mining in this area on SKYLAB imagery although some contour mining could be delineated with stereo viewing of the high altitude aircraft photography. The SKYLAB color infrared imagery proved moderately good for identification of areas which had been revegetated although distinguishing between different degrees of vegetal cover was difficult. This imagery clearly differentiates water bodies from coal mines refuse and slurry ponds. Highwalls were also identified where high contrast existed between the mined area and the surrounding vegetation. Consecutive S-190B image frames were studied stereoscopically, but the relatively low relief in the area minimized the advantage of the third dimension. It did provide binocular image reinforcement and an apparent improvement in image quality.

The six categories of mined land reclamation and features identified on the LANDSAT Band 7 enlargement of the

same area (Figure 14 overlay) included some highwalls, mined lands with 50% or more vegetative cover, mined lands with less than 50% vegetative cover, mined lands with essentially bare soil or rock, unmined lands, and water bodies or coal mine refuse areas. The quality of the LANDSAT imagery severely deteriorated at the 1:80,000 scale enlargement, but it still showed high contrast between the mined and unmined areas and proved valuable for rapidly mapping lands disturbed by surface mining. The superior resolution of SKYLAB imagery, however, provided greater detail in delineation.

Disadvantages of LANDSAT imagery as compared to SKYLAB include the lack of resolution of distinguishing cultural features to aid in transferring the data accurately to geographic base maps, the inability to distinguish between mine refuse areas, i.e. gob piles and slurry ponds and naturally occurring or other mining - related water impoundments. Other features associated with surface mining such as haulage roads, railroads, mine preparation plants, and areas being cleared or readied for surface mining were also difficult or impossible to identify.

The primary conclusion from this comparison is that once an accurate data base has been established from aerial photography, high quality LANDSAT imagery^{6/} enlarged to scales as much as 1:100,000, could be used to monitor and update data

^{6/}

Experience in the midwest area of the United States indicates that atmospheric vapor or haze seriously degrades much of the LANDSAT imagery, and that an image of superior clarity may be acquired only once or twice a year.

on surface mining activity; basically for the extension of new mining activity and monitoring the progress of revegetation. Repetitive orbital imagery with resolution approximating the S-190B camera would provide significantly superior data for monitoring mining and reclamation activities.

A portion of the SKYLAB S-190B color infrared imagery was also enlarged to a scale of 1:24,000. The greater clarity and contrast of vegetation boundaries on the color infrared imagery (EK 3443) rendered an enlargement considerably superior for analysis to the S-190B color film (SO-242) enlargement of the Sullivan test site. However, the resolution and contrast of these enlargements were not adequate to provide the accuracy of mined land delineations deemed necessary for most state requirements. It did, however, within the accuracies possible, provide substantial data for updating the existing 1:24,000 scale mined lands map produced from the high altitude aerial photography acquired 2-1/2 years before (Figure 12).

3.4 Non-Fuel Type of Mining

Within the Indiana test area non-fuel mining consists of clay mining for brick and ceramic product manufacturing, and sand and gravel quarrying for construction purposes. The clay mining is largely restricted to the area north of Terre Haute, whereas, sand and gravel mining occurs throughout the area along the floodplains of the major streams. This is especially common south of Terre Haute.

The clay mines in the test area are small, ranging in size from 1 to 5 acres, and many of the mines are no longer operational. The small size in conjunction with natural revegetation makes identification of the quarries difficult or impossible if the location is not previously known. Sand and gravel pits, particularly along the Wabash River are of greater areal extent, making identification easier. The typical lobate configuration of mining and the associated water bodies provide a distinctive pattern readily recognizable by an image analyst.

Sand and gravel quarries were identified with the greatest accuracy on the S-190B color images. Of the S-190A photography evaluated, the best resolution and contrast were obtained in the red band. Although it would have been desirable, color infrared imagery was not available for evaluation. However, based on a comparison between the S-190B color infrared photography from SL-3 mission acquired over the Kentucky site, and the S-190B color imagery from SL-2 mission of the Indiana test site, the latter exhibits the substantially better resolution.

Sand and gravel quarries larger than about 1/8 mile square were identifiable. For the larger quarries, which exceed 1/2 mile square (Figure 15) it was not possible to accurately evaluate their operational status with imagery from a single overpass. However, the higher reflectance of freshly exposed sand (point C) in comparison to areas where some vegetational growth has been established (point A) is indicative of recent operations. Such judgments are not precise, as it may take several years for substantial revegeta-

tion to occur on the waste surfaces. Repetitive coverage with SKYLAB type sensors would solve this problem. A comparison of this S-190B image (Figure 15) with aerial photography acquired in 1971 shows substantial changes in configuration and areal extent of quarries B and C, but no discernable change in the appearance of quarry A.

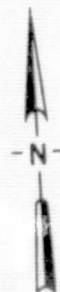
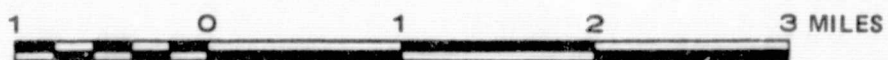


FIGURE 15. This 1:63,360 enlargement of a portion of S-190B image (No. SL-2, 81-338) is of the Wabash River floodplain about 30 miles south of Terre Haute. Numerous sand and gravel quarries are located in this area. Quarries B and C appear to be actively operated. Quarry A, due to the less reflective surface, is judged to be partially revegetated and no longer operating.

4.0 RESULTS

4.1 General

Imagery provided by SKYLAB has generated new data for state, federal and private industry groups concerned with natural resource extraction and management in Indiana. These data include fracture and lineament information for mine safety and petroleum exploration applications, new surface geological data, mined land detection, and reclamation assessments for lands strip mined for coal as well as for other mineral resources.

A comparison of the utility of EREP image products for fracture and lineament analysis, soil and vegetation zone mapping and mined land mapping is shown in Table 2. The S-190B color, color infrared, and S-190A, red band (600-700nm) films proved of greatest utility although nearly all of the other sensors provided at least some unique and useful information.

4.2 Utility of SKYLAB Data for Lineament Mapping

Many of the lineaments observed on the LANDSAT and aircraft imagery were also noted on the SKYLAB imagery. Some of these lineaments were better expressed and could be extended further on the SKYLAB imagery than on either LANDSAT or aircraft data. The lineaments mapped on SKYLAB imagery, which were not seen on the LANDSAT or aircraft imagery, generally corresponded closely in both trend and length to the linear features which had been previously mapped in the same area.

TABLE 2. Comparison of the utility of EREP image products for fracture detection, soil tone and vegetation contrast mapping, and mined land mapping capabilities.

Film Type	Fracture Detection Capability	Soil Tone Vegetation Contrast Mapping Capability	Mined Land Mapping Capability
S-190A-07 Pos. Transp.	X	XX	X
S-190A-08	XX	XX	X
S-190A-11	XXX	XXX	XXX
S-190A-12	XX	X	X
S-190A-07 Neg. Transp.	XX	XXX	X
S-190A-08	XX	XX	X
S-190A-11	XXX	XX	XX
S-190A-12	XX	X	X
S-190B Color	XXX	XX	XXX
S-190B Color Infrared	XXX	XXX	XXX
S-192 Multispectral Scanner (all bands)	X	X	(Not processed over coal mining portion of test site)

EXPLANATION

Spectral Bands

S-190A-07 700-800 nm
S-190A-08 800-900 nm
S-190A-11 600-700 nm
S-190A-12 500-600 nm
S-190B Color 400-700 nm
S-190B Color IR 500-900 nm

Film Utility Rating

X = poor detectability
XX = good detectability
XXX = excellent detectability

Numerous lineaments and fracture traces were detected on both color, color infrared and black and white transparencies. A large percentage of the cultivated lands were in a fallow state at the time of the SKYLAB-II overpass (June 10, 1973); this permitted the detection of fractures expressed in soil tone differences. Much of these data were not detected on LANDSAT imagery of comparable season or high altitude aircraft color infrared photography. Stream segments controlled by fractures, lineaments, and joint systems could be identified in much more detail on SKYLAB photography than with LANDSAT imagery of comparable scale. It is believed that the additional data derived, which was not noted on the aircraft or LANDSAT imagery, was detected by virtue of the higher resolution of the SKYLAB imagery. Other contributing factors may have been unique seasonal and climatic conditions that existed at the time of the SKYLAB overpasses and the synoptic view character of the SKYLAB imagery as compared to aerial photography.

4.3 Mined Land Inventory and Reclamation Assessment

4.3.1 Surface Mining for Coal

EREP imagery provides more data for mined land inventory and reclamation progress than comparable scale LANDSAT imagery. The higher resolution of both the color and color infrared photography proved superior when compared to LANDSAT data for defining differences in mined land vegetative cover, delineating areas of freshly stripped or abandoned unreclaimed mined land

(orphaned lands), mine refuse piles and slurry impoundments. Thus, SKYLAB imagery provides an accurate data base from which mined land changes can be updated by the use of successive LANDSAT or EREP overflights.

4.3.2 Evaluation of SKYLAB Imagery for Nonfuel Surface Mining

A review of EREP color photographs (1:1,000,000 and 1:500,000 scales) permitted the identification of a substantial number of nonfuel (sand, gravel, and clay) mines within the southern Indiana test area. Comparison with historical (1970 and 1971) small scale aerial photographs revealed significant changes in mined area and other evidence of active (or recently active) mining sites.

Although the size of most of these mines is relatively small, they are numerous, especially in areas where high quality sand and gravel deposits exist. Many of these mines operate for relatively short periods of time. Therefore, the detection and monitoring of these smaller surface mines can be an important contribution to state groups concerned with resource, reclamation, and land use management if a satellite with SKYLAB system resolution can provide coverage on a repetitive basis similar to that of LANDSAT.

5.0 CONCLUSIONS

This investigation evaluated the applicability of a variety of sensor types, formats and resolution capabilities to the study of both fuel and non-fuel mined lands. The results of this investigation should prove useful in designing the sensor packages of future orbital platforms to enable maximum data yield for mined lands applications.

- The image reinforcement provided by stereo viewing of the EREP images proved useful for identifying lineaments and for mined lands mapping. SKYLAB S-190B color and color infrared transparencies were the most useful EREP imagery for the investigation, especially for detailed mined land evaluation.
- New information on lineament and fracture patterns in the bedrock of Indiana and Illinois extracted from analysis of the SKYLAB imagery has contributed to furthering the geological understanding of this portion of the Illinois basin. A close relationship exists between the directions of lineaments mapped from the SKYLAB, ERTS and aircraft imagery. Additionally, SKYLAB imagery revealed many new lineaments and fracture trends were not detected on either the LANDSAT or the aircraft imagery.

- SKYLAB imagery (S-190A and S-190B) has demonstrated an application to the various aspects of surface mining disturbances. Eight categories of mined land disturbance were readily and accurately delineated from the SKYLAB imagery, whereas six categories of mined land disturbances could be mapped only roughly from the LANDSAT imagery.
- SKYLAB S-190B color and color infrared images proved the best EREP products for lineament and fracture detection, soil tone and vegetation mapping, and for mined land reclamation assessment. Of the S-190A photography, the red spectral band (600-700 nm) was nearly as useful as the S-190B imagery for lineament and fracture analysis, although the season of image acquisition probably increased the utility of this spectral band for lineament mapping to a greater extent than the S-190B products.
- The resolution and overall image quality of SKYLAB S-190B imagery is substantially better than LANDSAT imagery. Useful data were derived from SKYLAB images enlarged to as much 1:24,000 scale. Meaningful data for these studies from LANDSAT imagery were restricted to enlargements of 1:100,000 scale or smaller.

- Data acquisition on a frequent repetitive cycle, such as or more frequent than the 18 days of LANDSAT, plus the computer compatibility of the data is a definite requirement for change detection, particularly for regulatory monitoring of surface mining.
- The higher resolution of SKYLAB imagery over that of LANDSAT permits the identification of cultural features as an aid in accurately transferring the data to geographic base maps and the ability to accurately distinguish between mine refuse areas, such as gob piles and slurry ponds, and naturally occurring or strip mine-related water impoundments. Other features associated with surface mining such as haulage roads, railroads, mine preparation plants and areas being cleared or readied for surface mining can be more accurately identified on SKYLAB imagery.

An important overall conclusion of this investigation is that repetitive orbital imagery approaching the resolution of the S-190B camera would provide much useful data for monitoring surface mining and updating mined land maps. This will be especially true after accurate base maps have been compiled from analysis of aerial photographs. Such imagery could probably be employed to monitor revegetation and grading activities with an adequate degree of accuracy to aid in the enforcement of many of the state reclamation laws. This is particularly significant in view of the rapidly escalating operating costs of state mined land regulatory agencies and the need to more frequently acquire mined lands data in response to accelerated mining activities.

APPENDIX

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